Lessons Learned for Safe and Sustainable Lunar Exploration: The Case of KPLO Operations

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Contents

Introduction to KPLO Spacecraft

Item	Parameters
Mass	≤ 678 kg
Bus Power @ EOL	Average 760 Watt, (2-wing, 1-axis S/A)
Main Bus Voltage	26.4 ~32.8V unregulated
Mission Life	4 Months (Transfer-orbit) + 12 Months (Mission-orbit, include commissioning a month)
Lunar Transfer Trajectory	Ballistic Lunar Transfer(BLT) / Week Stability Boundary(WSB)
Mission Orbit	Altitude : 100 ±30km Mean Inclination : 90± 0.25deg
Propulsion System	Monopropellant System OMT : 30N Thruster (4EA) ACT : 4.45N Thruster (8EA)
Communication	S-band(Uplink) : 0.5Kbps, 1.0Kbps S-band(Downlink): 1.024Kbps, 16.384Kbps X-Band(Downlink): 8.5Mbps @HGA

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Introduction to KPLO Mission

KPLO Magnetometer (KMAG)
Kyung Hee University
Magnetic strength of lunar environment

KPLO Gamma Ray Spectrometer (KGRS)
Korea Institute of Geoscience and Mineral Resources
Spatial distribution of major elements (Chemical Composition)

Delay Tolerant Network Experiment Payload (DTN-PL)
Electronics and Telecommunications Research Institute
Interplanetary internet communication technique (Demonstration)

ShadowCam (SHC)
Arizona State University / NASA
Investigation of permanent shadow regions

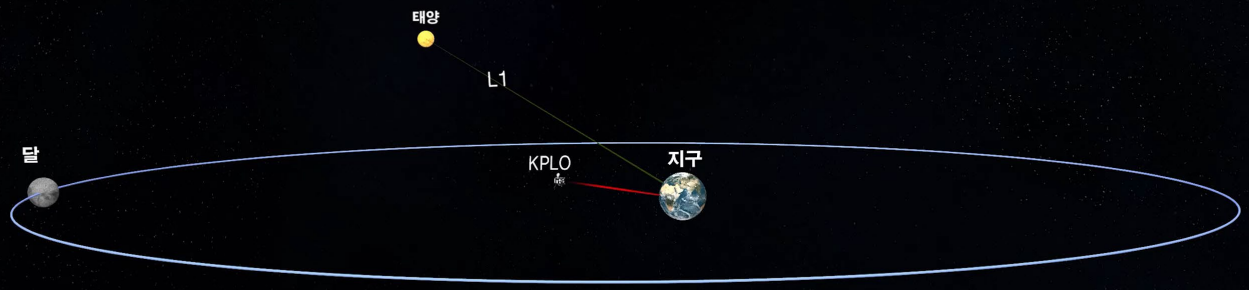
Wide-Angle Polarimetric Camera (PolCam)
Korea Astronomy & Space Science Institute
Polarimetric Image and titanium map of Moon

Lunar Terrain Imager (LUTI)
Korea Aerospace Research Institute
High-resolution lunar surface image (Korean Lunar Lander)

KPLO's Journey to the Moon

WSB/BLT Trajectory
Weak Stability Boundary / Ballistic Lunar Transfer

- Flight for about 133 days before LOI
- 4 Trajectory Correction Maneuvers
- 3 Lunar Orbit Insertion Maneuvers



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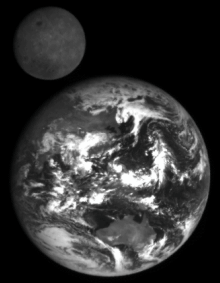
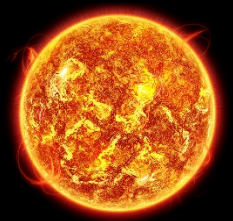
KPLO's Journey to the Moon

'22.12.24
'22.12.31
Earthrise

'23.1.6~2.4
Capturing Earth's phase change over a month

'22.9.15~10.15
Capturing the moon orbiting the Earth for 1 month





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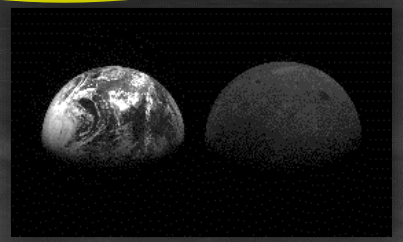
'22.8.26 First Imaging by Danuri

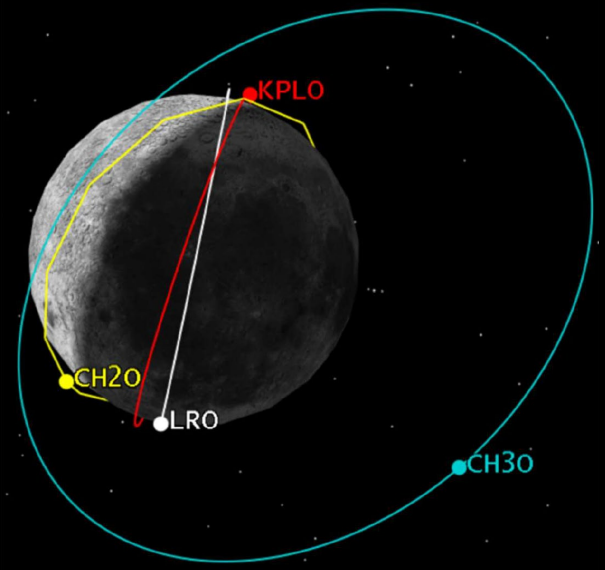


'22.11.24 Capturing the Earth and the Moon in similar size

① LV Separation (8/5)
② S/A Deployment & Sun Pointing (8/5)
③ HGA Earth Pointing (8/6)
④ TCM#1 (8/7)
⑤ TCM#3 (9/2)
⑥ TCM#5 (11/2)
⑦ TCM#6 (11/16)
⑧ LOI#1, #2, #4 (12/16, 21, 26)

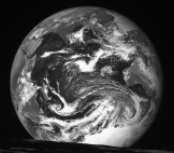
Operational Challenges and Solutions

- Currently, six lunar orbiters are in operation.
- Three orbiters (LRO, KPLO, CH2O) are in similar altitudes of low lunar orbit.
- We monitor collision possibilities daily through the MADCAP* Report provided by NASA JPL.
- Several missions share predicted ephemeris with JPL support.
- Collision probabilities are calculated and shared based on the predicted ephemeris of the missions.
- When collision risk between two spacecrafts increases and a Red Alarm is triggered:
  - Discussions take place.
  - Mitigation measures are developed and implemented.
- Collision risk may naturally diminish over time as orbit predictions become more accurate.
- If not resolved, a collision avoidance maneuver may be performed.



Oct. 12, 2023

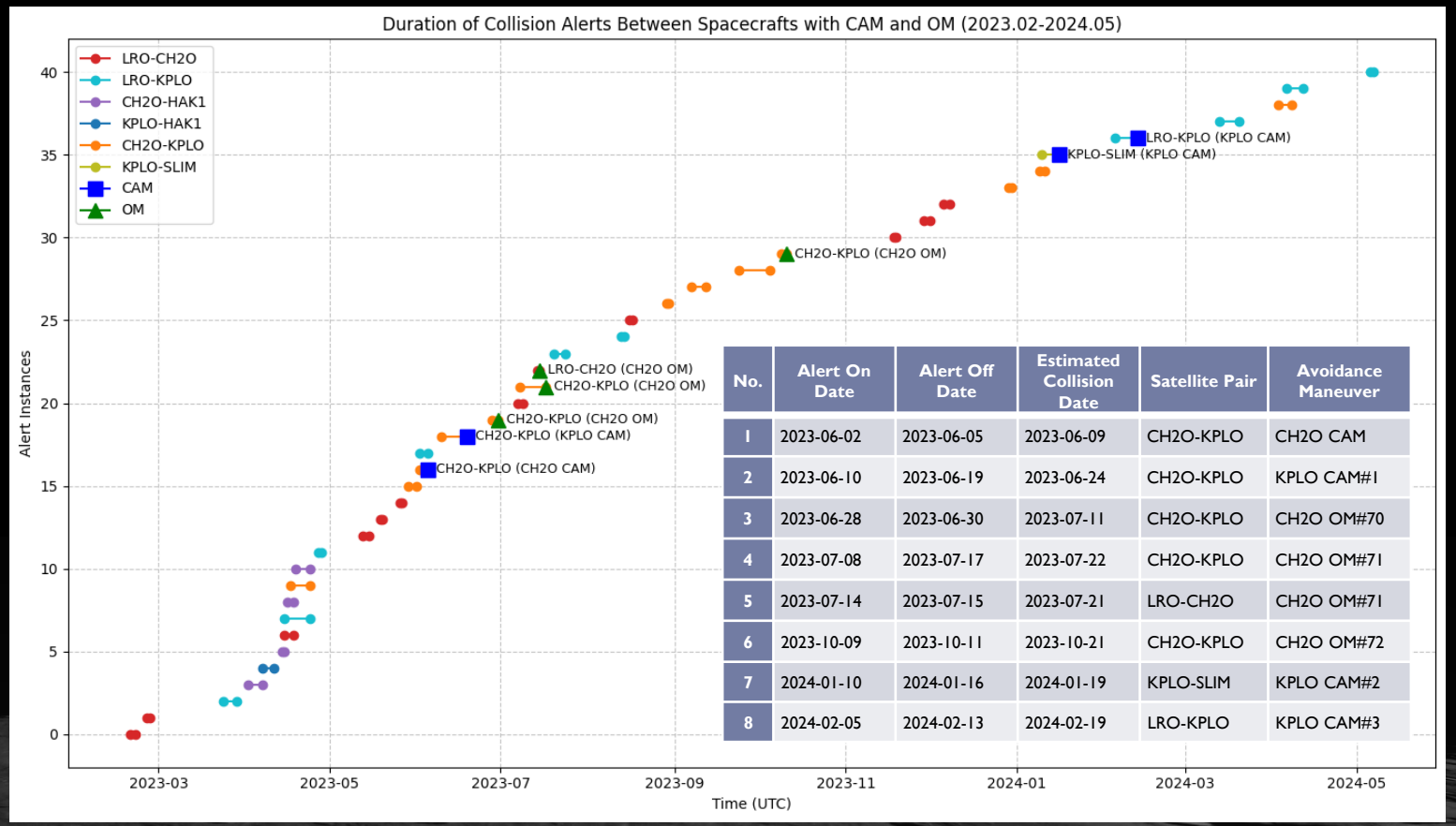
Spacecraft	Launch Date	Orbit Type	Altitude	Inclination Angle
ARTEMIS P1	Feb 17, 2007	Equatorial Lunar Orbit	Periapsis ~100 km, Apoapsis ~19,000 km	Equatorial
ARTEMIS P2	Feb 17, 2007	Equatorial Lunar Orbit	Periapsis ~100 km Apoapsis ~19,000 km	Equatorial
Lunar Reconnaissance Orbiter (LRO)	Jun 18, 2009	Polar	~50 km (initially circu lar, now elliptical)	90°
Chandrayaan-2 Orbiter	Jul 22, 2019	Polar	~100 km	90°
Korea Pathfinder Lunar Orbiter (KPLO)	Aug 4, 2022	Polar	~100 km	90°
CAPSTONE	Jun 28, 2022	Near-Rectilinear Halo Orbit (NRHO)	Varies	90°



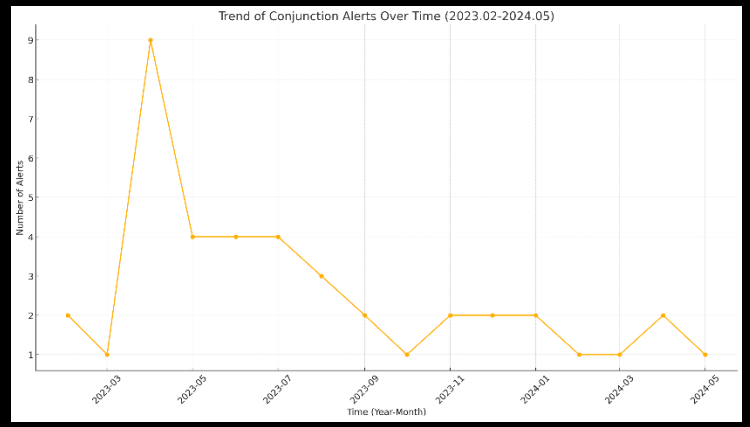
* MADCAP: Multimission Automated Deepspace Conjunction Assessment Process (by JPL)

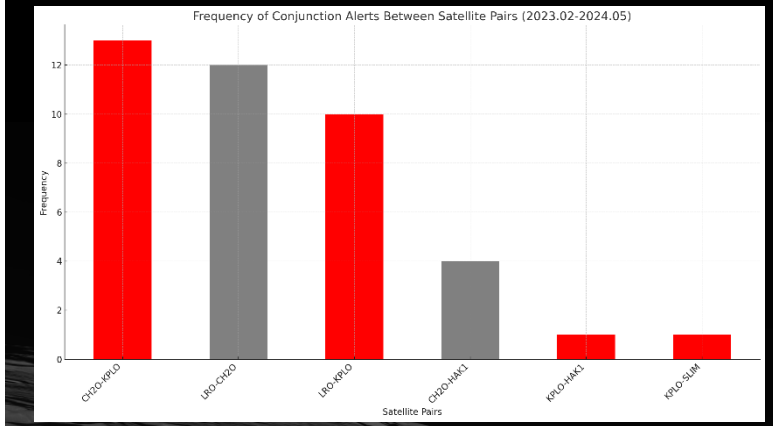
Collision Alert History (Red Alarm)

- From February 19, 2023, to May 7, 2024, a total of 41 Red Alarms were triggered.
- Collision risks were mitigated through 4 orbit maintenance maneuvers and 4 collision avoidance maneuvers.



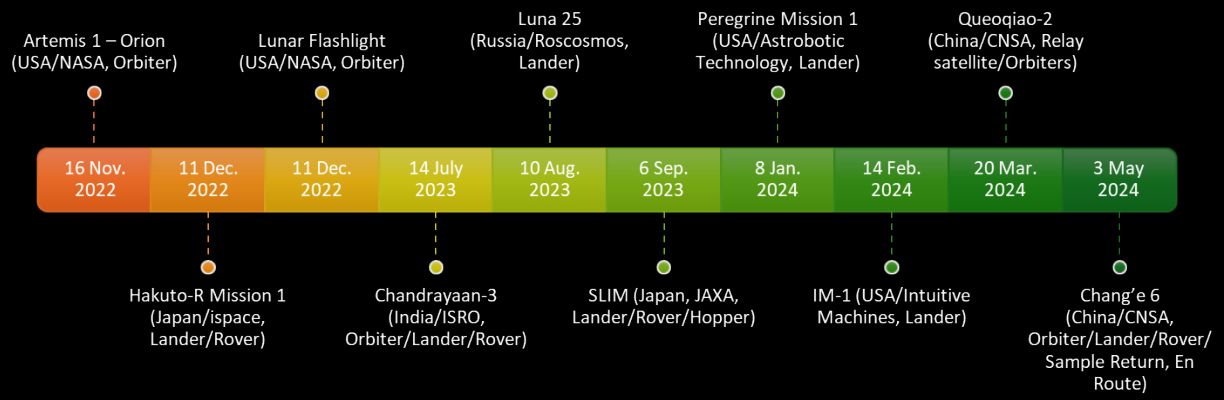
No.	Alert On Date	Alert Off Date	Estimated Collision Date	Satellite Pair	Avoidance Maneuver
1	2023-06-02	2023-06-05	2023-06-09	CH2O-KPLO	CH2O CAM
2	2023-06-10	2023-06-19	2023-06-24	CH2O-KPLO	KPLO CAM#1
3	2023-06-28	2023-06-30	2023-07-11	CH2O-KPLO	CH2O OM#70
4	2023-07-08	2023-07-17	2023-07-22	CH2O-KPLO	CH2O OM#71
5	2023-07-14	2023-07-15	2023-07-21	LRO-CH2O	CH2O OM#71
6	2023-10-09	2023-10-11	2023-10-21	CH2O-KPLO	CH2O OM#72
7	2024-01-10	2024-01-16	2024-01-19	KPLO-SLIM	KPLO CAM#2
8	2024-02-05	2024-02-13	2024-02-19	LRO-KPLO	KPLO CAM#3

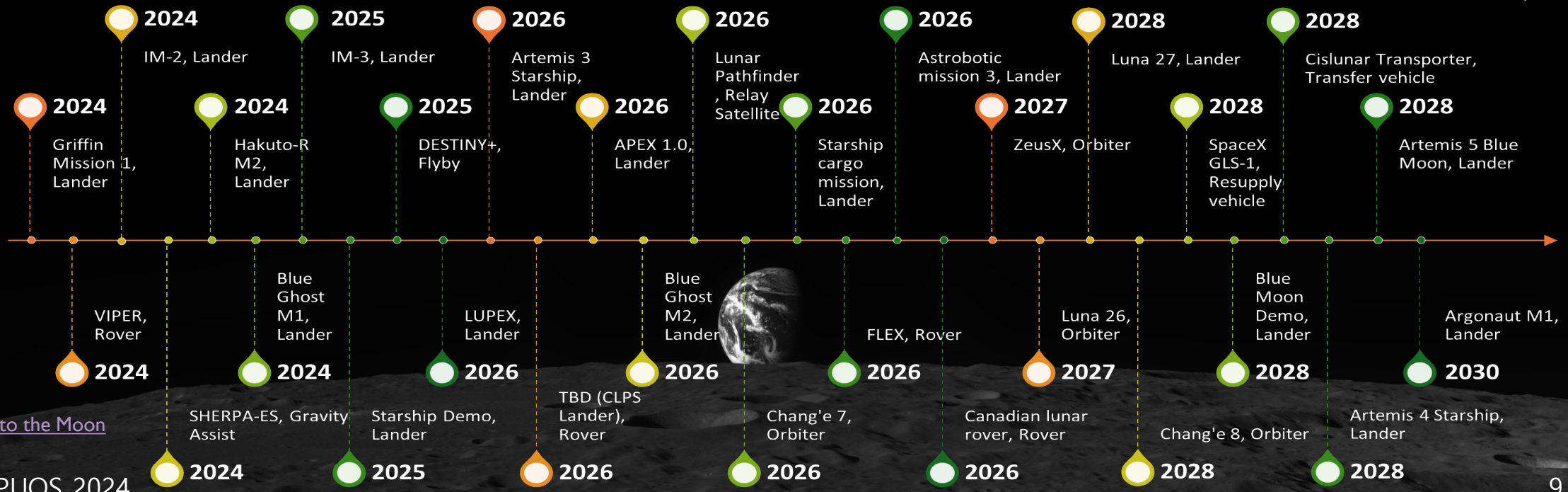




Necessity of International Collaboration for Future Missions

- Since the launch of KPLO, a total of 10 lunar missions have headed to the Moon.
- It is known that approximately 30 lunar missions are planned for the next six years.
- At this point, it is time to start discussions on international cooperation regarding the increasingly crowded lunar orbit.

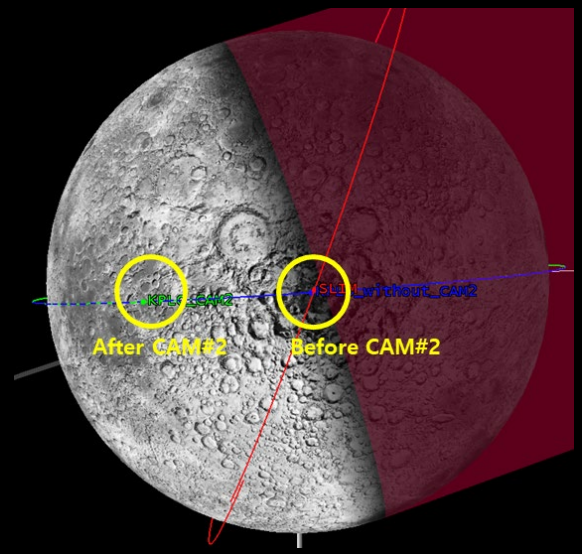




Data Source:
List of missions to the Moon - Wikipedia

Lessons Learned from KPLO Mission

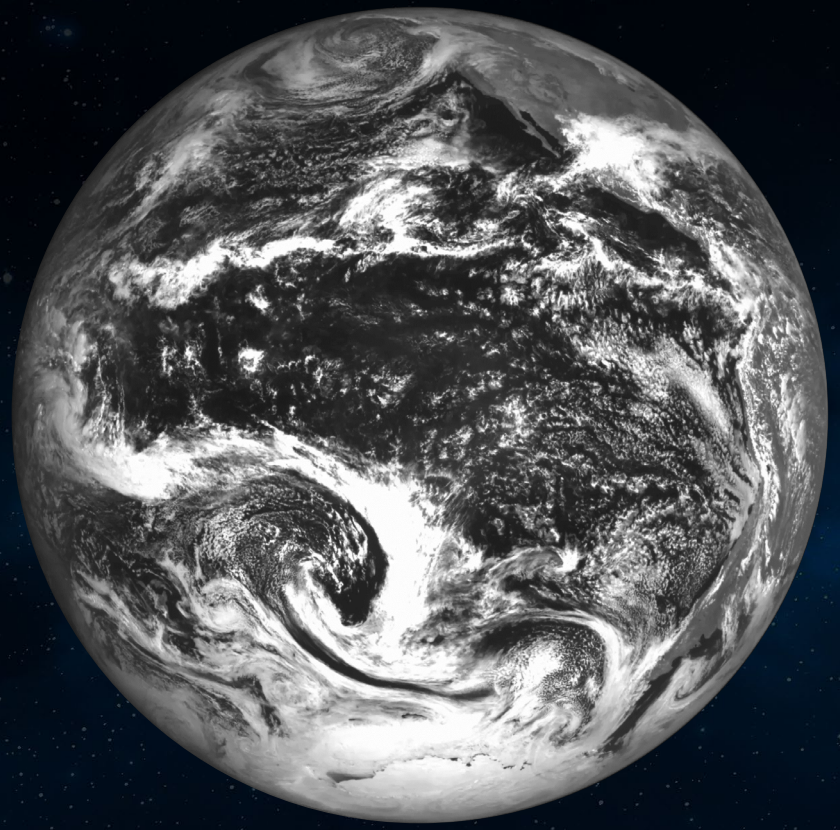
- Collision avoidance maneuvers require fuel consumption and temporary suspension of some payload mission, which may lead to differences in opinion regarding who should carry them out.
- Due to the absence of an international protocol among all agencies for resolving collision risks, we have been coordinating solutions through discussions, including email exchanges and teleconferences.
- Sometimes, we did not have the contact information of the responsible personnel, and network security issues occasionally prevented email exchanges. However, we ultimately resolved all collision risks through collaborative discussions.
- When KPLO had options, we considered how we could contribute most effectively.
- During the time SLIM was landing, urgent conjunction discussions took place, and KPLO's decision to perform collision avoidance maneuvers helped ensure SLIM's safe operations.



"Your proactive approach and dedication not only ensured the safety of both spacecraft but also exemplified the spirit of cooperation and collaboration between our institutions. We deeply appreciate your commitment to safety."

- Letter from KUNINAKA Hitoshi
Director General, ISAS

Thank You For Your Attention



'23.11.13 Earth Rotation taken by LUTI
(Post processed)

KPLO Korea Pathfinder Lunar Orbiter

Korea's First Lunar Exploration Mission

Korea Aerospace Research Institute